Research & Development at Intel

Accelerating the Convergence of Computing and Communications

www.intel.com/technology

At the heart of the convergence.

"Convergence for Intel is as much about the coming together of two technologies to produce a third – something we call micro-convergence – as it is about the role newly created technologies play in driving new business models, and ultimately new societal norms and behaviors that collectively represent macro-convergence. Intel's research and development work is at the heart of both. We're collapsing communications and computing onto the same die, allowing Intel to dramatically reduce the cost, drive up the integration, and improve the performance of a new generation of converged products. We're also building the foundation for an explosion of innovation.

And the best is yet to come."

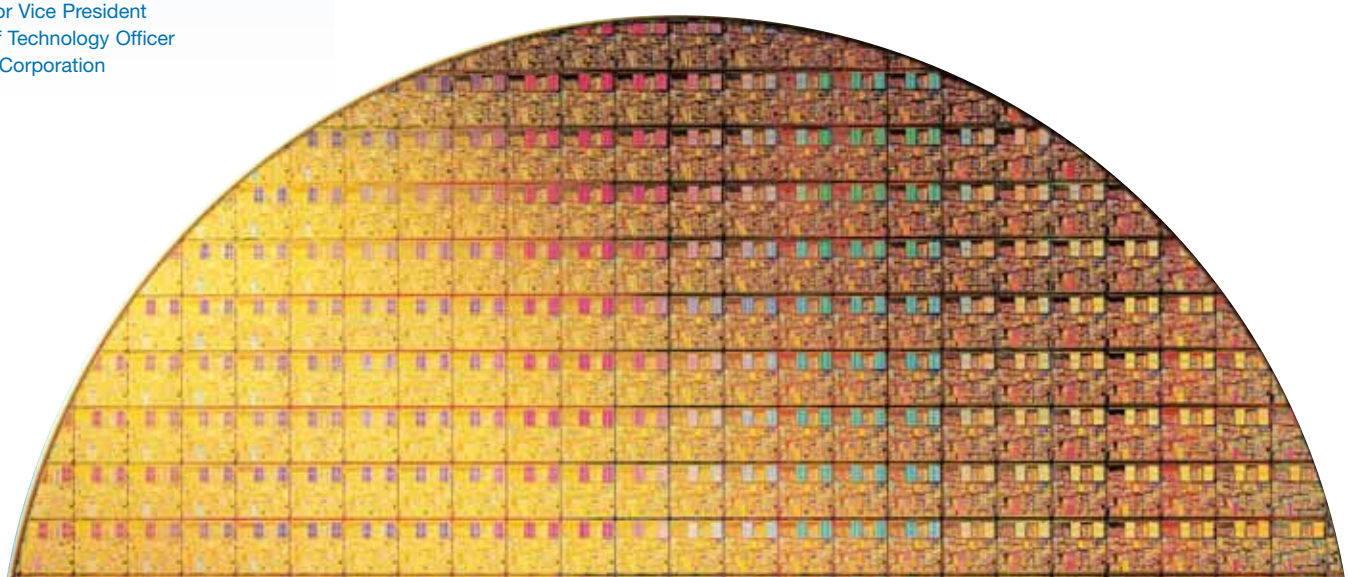
Patrick P. Gelsinger
Senior Vice President
Chief Technology Officer
Intel Corporation

Envision, explore, enable...

Intel supplies the fundamental technology building blocks for the computing and communications industries, so our research and development has an impact far beyond our own corporate walls. Intel's breakthroughs exert a multiplier effect, enabling opportunities for thousands of companies that create products and solutions based on them – and empowering millions of businesses and consumers who ultimately use and rely on them.

Intel has a long record as a research and development powerhouse whose efforts catalyze widespread innovation. Intel's research, development, and manufacturing technology have made Moore's Law[1] appear to be a self-fulfilling prophecy, spawning a dynamic industry whose rate of advance has no equal. Intel technologists have developed core technologies that have changed the industry such as the Intel® processor architecture, Ethernet, Peripheral Component Interconnect (PCI), and Universal Serial Bus (USB). These, along with many other technologies, have become industry standards paving the way for rapid progress.

As communications and computing converge, Intel is uniquely positioned to accelerate the shift to a new world of services and information access anywhere, any time, on any device – through our integrated silicon design and manufacturing, advanced computing and communications technology and product building blocks, investments that catalyze and advance the industry, and our leadership in establishing industry standards and technology policy worldwide. Together, these capabilities drive Intel's ability to address the broad range of technical challenges and industry opportunities that are a part of this converged future.



Intel technology focus areas

At Intel, our research and development work is organized around five technology focus areas: silicon technology and manufacturing, microarchitecture and circuits, communications and networking, computing platforms and software. They, and the innovations and breakthroughs they produce, represent the core strengths of Intel.

Silicon technology and manufacturing

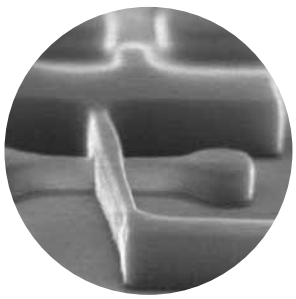
Breakthroughs in silicon technology and manufacturing keep Intel one generation ahead of our competitors and deliver competitive advantages to companies that base their products on the Intel® architecture. Intel's leadership in silicon technology both extends Moore's Law, increasing performance while reducing manufacturing costs, and expands Moore's Law, bringing new capabilities into silicon and producing new products optimized for a wider variety of applications.

■ While the rest of the industry slowly transitions to 130 nanometer[2] (nm) process technology, Intel is already in production with its **90nm process** generation. Featuring the world's smallest complementary metal oxide semiconductor (CMOS) transistors in volume production and incorporating new materials, such as strained silicon to reduce power consumption, Intel's 90nm process platform significantly improves device performance, power efficiency, and capabilities integration. Our 65nm process is already in prototype.

■ Intel's **tri-gate transistor** features a unique 3-D gate structure that improves power efficiency and device scalability. Silicon chips based on the tri-gate transistor will deliver faster switching speeds, lower power, and less current leakage resulting in higher performance and longer battery life. Intel technologists have moved the tri-gate transistor into advanced development in preparation for its first production in 2007.

"Intel will continue to drive Moore's Law through advanced nanotechnology. Our research goes well beyond this year's 90nm technology to evaluate options that extend silicon technology into the next decade."

Sunlin Chou
Senior Vice President
General Manager,
Technology and
Manufacturing Group
Intel Corporation



Intel 30mm Tri-gate Transistor

Fractional-N Frequency Synthesizer – the silicon heart of an adaptive radio

Microarchitecture and circuits

Intel's work in component and circuit design techniques lays the groundwork for advances in microarchitecture and system architecture concepts for future Intel® platforms. Balancing performance and power is a particular focus, with researchers in our Microprocessor Research Lab exploring novel and innovative approaches, including on-die implementation of body bias techniques and sleep transistors to reduce power and leakage, circuit designs that employ probabilistic techniques to account for transistor performance variance, and microarchitectures that use multithreading and multi-core design approaches to improve performance.

■ Running in excess of 10 GHz, the **protocol offload engine** is an experimental hardware processor core designed to offload TCP/IP stack processing from a system's main processor. Tests show that, without help, today's general purpose processors will be as much as 90% consumed servicing high speed communications such as 10 Gbps Ethernet. Using this type of special-purpose, task-optimized hardware, Intel would provide system designers increased system and communications performance while delivering better MIPS/Watt operation and greater efficiency.

■ By combining our world-class silicon process technology and CMOS circuit design expertise, Intel is well on its way to producing the necessary RF passives, multi-band analog front end (AFE) and reusable digital baseband/media access control (MAC) elements for an all-digital **adaptive radio** solution. Intel recently demonstrated a prototype of an all CMOS 10 GHz frequency synthesizer, arguably the heart of an adaptive radio, that is based on a 5 GHz CMOS voltage-controlled oscillator (VCO) and features phase noise specified as –120 dBc at a 1 MHz offset. This is one of several key developments aimed at realizing the vision of Radio Free Intel (see sidebar on page 4).

1. Intel cofounder Gordon E. Moore's 1965 prediction about the continued doubling of transistor density and hence performance.
2. A nanometer is a billionth of a meter.

Radio Free Intel

Enabling ubiquitous silicon-based wireless connectivity.

About more than just the integration of radio communications capability into our processors and chipsets, this visionary Intel initiative will make it easy and inexpensive to enable adaptable wireless connectivity in every conceivable type of product – from PDAs, notebooks and cell phones to consumer electronics, appliances, and even clothing and furniture. Making wireless connectivity transparent and ubiquitous will help drive new revenue opportunities for the communications industry by offering business and consumers greater access to more useful information and services anytime, anywhere on any device they choose.

To meet the requirements and challenges inherent in realizing this ambitious vision, Intel is focused on providing low-cost, low power silicon radio building blocks, collaborative development of a comprehensive platform-level solution for an adaptive radio architecture, and global adoption of appropriate and favorable standards and regulatory policies. By combining our silicon technology and manufacturing expertise with research and development efforts spanning key application segments, technologies, and industry enablement issues, Radio Free Intel will power a future where ubiquitous wireless connectivity is as central to our lives as the automobile is today.

Building tomorrow's te

Communications and networking

Intel develops technologies, specifications, and standards for future wireless connectivity, home and enterprise networks, and Internet and telecommunications infrastructure. Projects range from next-generation Ethernet specifications for the networked enterprise and emerging wireless applications, to ad hoc networking technologies for wireless communication over heterogeneous sensor networks.

- Intel is a leader in the effort to catalyze the specification for **Ultra Wideband (UWB) radio**, a new industry standard that promises to revolutionize high-speed data transfers. Intel is also creating technologies for the UWB-enabled personal area networks, fostering more robust, lower-cost radio architectures and new user services.

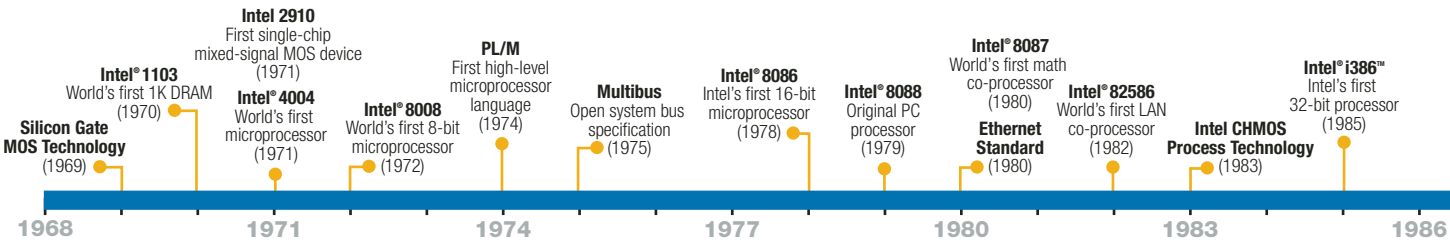
- Intel's research work is enabling self-organizing wireless **sensor networks** that monitor and relay critical information about the environment around them in a broad range of applications including agriculture, conservation, and industrial production. By integrating low-power processing, storage and wireless communications capabilities, Intel® mote technology provides the tiny, self-contained, battery-powered computing building block upon which these sensor networks are based. To aid in the deployment of these prototype sensor hardware platforms, Intel Research, in collaboration with its UC Berkeley-affiliated research lab, is developing and promoting advanced packet processing technologies and software specifications for multi-hop sensor networks through open-source software such as TinyOS* and TinyDB.*

Intel® mote technology

Computing platforms

From Intel® Centrino™ mobile technology to Intel® PCA (Intel Personal Internet Client Architecture), Intel's platform innovations power today's convenient, lightweight computing and communications solutions.

35 thirty-five years of innovation → highlights



chnologies today

Intel defines and enables a wide range of hardware environments where our technologies and products are used. We also work with the industry to advance new technologies and introduce initiatives supporting new standards and usage models.

■ Deerfield, the next iteration of the **Intel® Itanium® 2 architecture**, targeted at dual-processor, lower-power-consumption systems, delivers industry-leading enterprise performance and requires just half the power of its predecessors. The next-generation IA-64 microarchitecture will also increase computing density by putting two processor cores on a single die. For more rapid adoption of our architectures and an improved software development environment for them, Intel also produces tools and technologies that are distributed through open source libraries and standards bodies. For example, Intel's **Open Research Compiler** is an advanced, high performance, open source compiler for the Intel® Itanium® 2 processor that Intel has donated to the open source community to assist in the development of optimized enterprise and mission critical software applications.

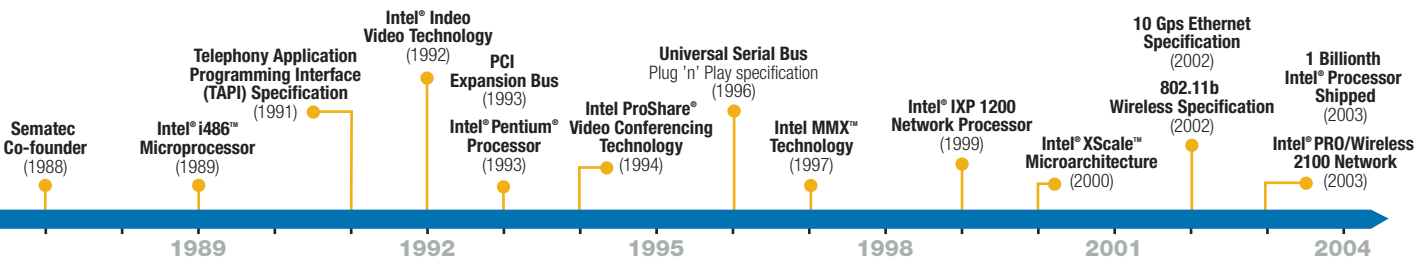
■ Intel's leadership in the PCI Express* (PCI-X) Special Interest Group has helped bring about such innovations as the **PCI-X Advanced Switching Architecture**, a standards-based specification for a scalable and extensible packet-switching fabric (or mesh) interconnect. Intel plans to roll out new building blocks and development tools based on PCI Express by the end of 2003 and the Advanced Switching specification in 2005.

Software

Software is vital to Intel's mission of accelerating convergence. Intel enables next-generation software capabilities that enhance application compatibility and ease solution development and deployment by providing technologies, tools, services, industry standards leadership, and support infrastructure for the software industry. In addition to developing software tools such as compilers, performance analyzers and threading tools, Intel's software research efforts are creating software environments to model future applications and compute workloads that are used by hardware developers to push the envelope toward better features and performance of silicon. As applications evolve towards convergence, Intel offers developers homogeneity for multiple environments, providing integrated specific instruction sets, tools and SDKs across Intel® silicon architectures.

■ **Managed Runtime Environments (MRTE)** make it faster and easier to develop applications by allowing them to run seamlessly and transparently to the user on a range of hardware devices with differing processor and operating system capabilities while applying advanced programming techniques. We have applied our microarchitects and microprocessor design team expertise to the development of new MRTE architectures and advanced MRTE software optimizations which formed the basis for a high quality and highly optimized experimental MRTE. Intel's Open Source Dynamic Computing Research Platform, developed by our Microprocessor Research Lab, is a platform for byte code system research, an open source research platform that allows interchangeable modules implementing Just-In-Time (JIT) compilers and Garbage Collection (GC). Our ORP (Open Runtime Platform) is an open source research infrastructure project that provides these features, thus enabling the rapid evolution of systems research in dynamic compilation and memory management.

■ Intel researchers use interface design as one tool to understand hardware performance and feature requirements for future usage platforms, workloads, and users. To enable industry participation in this process, Intel develops and makes available an extensive array of open source **performance libraries** for digital signal processing, speech recognition, image processing, computer vision, advanced 3-D graphics capabilities, and more.



Global innovation.

Great thinking happens around the world.

Intel's unique R&D model is based on a global, decentralized organization that emphasizes an open, collaborative approach to identifying and developing new technologies and driving standards and regulatory policy to accelerate their successful adoption.

To ensure the highest quality results, Intel strives to work with the best and brightest by going to where they are. Consequently, Intel has lab facilities located from Barcelona to Beijing and beyond. These local labs take advantage of local expertise and provide funding and expertise to university research projects in strategic emerging technologies that support their primary mission. For example, the Intel China Research Center is combining Intel's open computer vision libraries and tools with the latest algorithms in probabilistic computing to produce audio visual enabled speech recognition (AVSR), a set of platform technologies for use in building a more natural and intuitive interface.

Industry standards are an important catalyst for value-added innovation and growth. Intel's ongoing commitment to developing and promoting standards includes contributions of advanced technology, time and expertise, as well as their validation and promotion when integrated into our products. For example, Intel chairs the WiMAX Forum, a nonprofit group of more than 25 companies committed to promoting the new IEEE 802.16a wireless broadband standard and certifying the compatibility and interoperability of 802.16a equipment. Intel is also developing silicon products aimed at enabling 802.16a-compatible wireless broadband as a convenient lower cost alternative to existing "last mile" methods such as digital subscriber line (DSL) and cable. Other examples of Intel's standards leadership include 802.11 WiFi,* UPnP,* UWB, and the Internet Protocol Version 6 (IPv6).

Intel's R&D Enables an Industry

$4 billion

75+ Intel labs worldwide

7,000+ R&D professionals

Government bodies around the world look to Intel for advice and expertise in addressing policy and regulatory issues. Intel's R&D experts are members of the Federal Communication Commission's technology advisory council, and recently testified before the Senate Commerce Committee about frequency allocation policy and other wireless regulatory issues. Intel is also working regularly on similar matters with regulatory authorities in Singapore, Japan, China, Russia, and the European Union.

Keeping Intel and its customers at the

Intel technology applied

Using a market-driven approach, Intel technology drives innovation and enables new solutions for the digital home, mobility, communications and the enterprise. Here are some examples of each.

Advancing the digital home

A digitally enabled home makes accessing digital entertainment and information part of the fabric of daily living, with wirelessly networked PCs and consumer electronic devices working together to distribute, store, enhance, and share content ranging from family photos to DVDs. As a result, people will be empowered to experience the true benefits of digital media and communications throughout the home.

As a leader in enabling the digital home, Intel was a key player in forming the **Digital Home Working Group** to address roadblocks to digital content sharing among networked consumer electronics equipment, mobile devices, and PCs. The group shares a common goal of establishing a platform of interoperability based on open industry standards and will deliver technical design guidelines that companies can use to develop digital home products that share content through wired or wireless home networks. Consistent with this, Intel, in conjunction with Sony, Hitachi, and Matsushita, developed the **Digital Transmission Content Protection** (DTCP-IP) specification to enable easy and secure delivery of premium entertainment content such as movies and music over digital home networks. Intel also wrote the specification for, and operates the licensing entity that provides the means for implementors to build products based upon, **High-bandwidth Digital Content Protection** (HDCP) to enable a high-definition digital connection between your PC, DVD player, set top box and high definition TVs. And Intel technologists are now working on next-generation high definition content management solutions to bring even more compelling content to the digital home.

A key requirement for the digital home is the ability to easily store and access digital information across the ever growing class of digital devices such as MP3 players, digital cameras, and camcorders. **Universal Plug and Play (UPnP*)** specifications developed by Intel in partnership with the industry, provide device discovery and control protocols for digital media adapters and IP networks in the digital home to make them self configuring so consumers can just use them. Intel was a leader in the effort to develop UPnP standards, and today delivers chipsets that make them a reality. Intel is also exploring next-generation networking solutions based on **multi-hop** or **mesh networks** to enable wireless coverage to every nook and cranny of the digital home.

"Intel has consistently been willing to invest in R&D that will grow its market segments and to pay attention to the entire ecosystem through which its products deliver value to customers."

David L. Tennenhouse
Vice President,
Corporate Technology Group
Director, Intel Research
Intel Corporation

The digital home's potential to impact our lives extends far beyond entertainment, and Intel's ethnographers and technologists are exploring – and enabling – future usage models such as **proactive health**. By collaborating with organizations such as the Alzheimer's Association, this strategic initiative driven by Intel Research is exploring how an intelligent sensor network embedded throughout a digitally enabled home might improve quality of life and prolong independence for millions of people with Alzheimer's disease. Results look promising as a set of technologies that will improve life quality for all ages.

leading edge

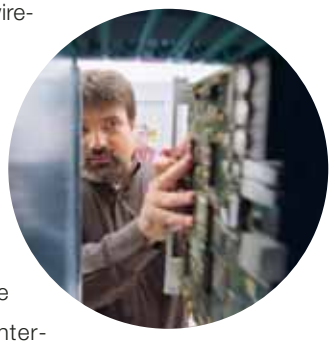
Building the wireless tomorrow

The future is wireless. And just as Intel spurred unprecedented innovation in the PC and server industries, Intel's commitment to mobility and wireless is enabling a mobile lifestyle that just works.

For example, Intel advanced the state of the art with the high-performance, power-efficient Intel® cellular processor, the **wireless "Internet on a chip"** that is at the heart of an advanced total system solution for today's GSM/GPRS mobile phones. This is the first product to fully integrate a GSM/GPRS baseband solution with a high-performance application processor and flash memory on a single chip. Integration of Intel® On-chip flash memory and SRAM into the processor yields both a significant increase in processing performance and a reduction in power consumption. This design enables the development of powerful, cost-effective wireless devices capable of running rich data applications.

Your PC's data and applications are what make your personal computer "personal." Intel envisions a new class of low-power mobile devices that combine advances in processing, storage, and communication technologies to offer anywhere, anytime access to personal information and applications. Coined the **personal server**, Intel's prototype of the smaller than PDA-class device combines high-density storage, low-power processing and short-range wireless capability for access to available displays. Intel is also developing the software necessary to support secure interaction between personal server and publicly available infrastructure, and exploring the effect such interaction might have on mobile computing usage models.

Communications infrastructure

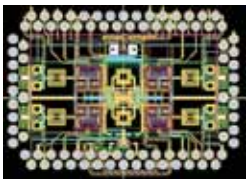


Convergence – and specifically the wireless enablement of all devices – drives an exploding demand for new communications capacity, equipment, and services. To support millions of new, connected wireless nodes, Intel's R&D is working to provide the communications industry with flexible, intelligent hardware components and standards-based interoperable platform solutions needed to build the wire line and wireless infrastructure this ever increasing demand requires.

For tomorrow's wire line infrastructure, Intel technologists are developing standards-based **modular communications platforms** that use intelligent processing in the network, carrier-grade operating systems, high-availability middleware APIs, and scalable I/O interconnects as the basis for scalable, flexible, and high performance networking solutions. Longer-term, Intel's silicon photonics research is focused on enabling dynamic electronic control and routing of optical signals using inexpensive silicon-based devices, an example of which is Intel's tunable laser. This device, which integrates the equivalent of up to 80 discrete devices

and is capable of tuning across the entire C-band in optical communications, reduces the number of lasers required at each node from many to only one thereby lowering total capital costs. Such devices, based on Intel's high-volume silicon manufacturing process, will make possible the cost-effective deployment of high speed, high capacity fiber-optic networks in new market segments and application types.

To accelerate the deployment of wireless infrastructure, Intel is developing a standards-based adaptive radio architecture that will support multiple radio protocols over multiple frequency bands[3] and wireless networks. Using a common flexible hardware base that includes a scalable mesh of heterogeneous processing elements and smart antenna systems, Intel's **reconfigurable communications architecture** (RCA) will enable smaller more power efficient devices with improved spectrum usage, throughput and signal range.



Multiple Antenna Array with integrated mixers/ combiners and amplifiers

Intel is also driving the regulatory guidelines and industry standards required for rapid deployment of new wireless communications infrastructure. In addition to driving development and industry adoption of wireless standards such as UWB, WiFi*, and WiMAX, Intel efforts are also focused on regulatory issues such as **open spectrum policy** and **radio module certification**, both critical to the long-term viability of adaptive radio solutions.

3. Such as Bluetooth*, 802.11, 802.15.3a (Ultra Wide Band), and wireless code-division multiple access (W-CDMA)

"Intel brings a depth of expertise in both the computational side and the communications side. Many projects are staffed by people who come from both backgrounds, and the synergy is valuable and exciting."

Kevin C. Kahn
Intel Fellow,
Corporate Technology Group
Director, Communications and Interconnect Technology
Intel Corporation

Next-generation enterprise

Intel's R&D spans a wide range of activities to enable tomorrow's networked enterprise, in which both datacenter and mobile and desktop clients will require more flexible, cost-effective, and secure hardware and software solutions.

Primarily intended for the next generation of IA-32 and Itanium® architecture-based computers, Intel's **Extensible Firmware Interface** (EFI) defines a new model for the interface between operating systems and platform firmware that is implementation neutral and legacy free. Based on research from our Network Architecture and Emerging Platforms Labs, future versions of the EFI specification will enable more flexible, cost-effective datacenter management through increased use of client-driven network boot, automated and remote provisioning techniques, and platform and network agents for secure reset and remote power cycling.

Intel is also at work on new, **object-based storage architectures** that treat storage as objects rather than blocks or files. This approach paves the way for more flexible storage area networks, higher-performance network-attached storage, and a more manageable datacenter.

And Intel's work in **self-healing networks** aims to make tomorrow's datacenters more secure. Each networked system can have an autonomous and trustworthy module that alerts a health control center of any potential problem. Self-healing network technologies also make future datacenters easier to manage and provision.

Working Together

Intel's success starts with an ongoing stream of outstanding building block technologies, but ultimately, it depends on fostering a robust innovation ecosystem and removing roadblocks that stand in the way of our customers' success. To ensure that success, we're investing $4B annually – to keep our products and technologies on the leading edge, catalyze an environment of rapid innovation, and enable our customers to create solutions, based on Intel product and technology building blocks, that delight consumers and deliver outstanding business value. Intel is laying the groundwork for the future.

Take advantage of Intel's hard work. Learn more about Intel's R&D activities. Understand how Intel's technology advances and industry enablement activities can create opportunities for your business, and engage with us on related research projects. Maximize your success and accelerate your time to market by using Intel architecture-based platforms and tools.

Together, we can build the future.

Keep up with Intel's R&D advances.

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